CLAIMS

I claim:

1. A method for determining a shear wave velocity of a subterranean formation, the method comprising:

(a) providing a downhole tool including at least one acoustic transmitter deployed at a first longitudinal position in a borehole and at least one acoustic receiver deployed at a second longitudinal position in the borehole;

(b) propagating a multi-pole acoustic signal in the borehole using the acoustic transmitter;

(c) receiving an acoustic waveform from the multi-pole acoustic signal at the at least one receiver;

(d) processing the acoustic waveform to determine a borehole guided wave velocity; and

(e) processing the borehole guided wave velocity to determine the shear wave velocity of the subterranean formation.

2. The method of claim 1, wherein the multi-pole acoustic signal includes at least two waveforms selected from the group consisting of monopole, dipole, and quadrupole waves.

3. The method of claim 1, wherein the multi-pole acoustic signal has a center frequency in a range selected from the group consisting of:

(1) about 5 kHz to about 9 kHz.; and

(2) about 6 kHz to about 8 kHz.

4. The method of claim 1, wherein the multi-pole acoustic signal has a bandwidth less than about 3 kHz.

5. The method of claim 1, wherein the multi-pole acoustic signal has a bandwidth less than about 1.2 kHz.

6. The method of claim 1, wherein the multi-pole acoustic signal has a center frequency in a range from about 6 kHz to about 8 kHz and a bandwidth less than about 1.2 kHz.

7. The method of claim 1, further comprising:

(f) filtering the acoustic waveform with a band pass filter, the band pass filter having a center frequency in a range from about 6 kHz to about 8 kHz and a bandwidth less than about 1.2 kHz.

8. The method of claim 1, wherein (d) comprises using an algorithm selected from the group consisting of a semblance algorithm and a phase velocity processing algorithm.

9. The method of claim 1, wherein (e) comprises:

processing a mathematical model to relate a theoretical shear wave velocity to a theoretical borehole guided wave velocity; and

processing the mathematical model and the borehole guided wave velocity determined in (d) to determine the shear wave velocity of the subterranean formation.

10. The method of claim 9, wherein the mathematical model is derived by solving wave equations for a slowness of a theoretical borehole guided wave.

11. The method of claim 9, wherein the mathematical model is dependent upon an azimuthal order of a theoretical borehole guided wave.

12. The method of claim 11, wherein:

theoretical shear wave velocities are determined for at least two of the azimuthal orders selected from the group consisting of monopole, dipole, and quadrupole waves; and

the shear wave velocity of the subterranean formation is determined by processing said theoretical shear wave velocities.

13. The method of claim 11 , wherein:

theoretical shear wave velocities are determined for a first borehole guided wave arrival for at least one of the azimuthal orders selected from the group consisting of monopole, dipole, and quadrupole waves;

theoretical shear wave velocities are determined for a second borehole guided wave arrival for at least one of the azimuthal orders selected from the group consisting of monopole, dipole, and quadrupole waves; and

the shear wave velocity of the subterranean structure is determined by processing the theoretical shear wave velocities from the first and second borehole guided wave arrivals.

14. The method of claim 9, wherein the mathematical model is dependent on at least one parameter selected from the group consisting of:

(1) a frequency of the multi-pole acoustic signal;

(2) a density of the subterranean formation;

(3) a density of a drilling fluid;

(4) a compressional wave velocity of the subterranean formation;

(5) a compressional wave velocity of the drilling fluid; and

(6) a diameter of the borehole.

15. The method of claim 14, wherein the frequency of the multi-pole acoustic signal is a center frequency in a range from about 6 kHz to about 8 kHz.

16. The method of claim 14, wherein the density of the subterranean formation is measured downhole in substantially real time using a spectral density measurement tool.

17. The method of claim 14, further comprising drilling fluid in the borehole, wherein density of the drilling fluid is calculated based on a nominal density of the drilling fluid and downhole measurements of at least one of temperature and pressure of the drilling fluid.

18. The method of claim 14, wherein a compressional velocity of the subterranean formation is determined from the acoustic waveform received in (c).

19. The method of claim 14, further comprising drilling fluid in the borehole, wherein a compressional velocity of the drilling fluid is calculated based on a nominal compressional velocity of the drilling fluid and downhole measurements of at least one of temperature and pressure of the drilling fluid.

20. The method of claim 14, wherein the borehole diameter is measured using an acoustic caliper tool.

21. The method of claim 1, further comprising:

(f) processing the multi-pole acoustic waveform to determine a compressional wave velocity of the subterranean formation.

22. A method for determining compressional wave and shear wave velocities of a subterranean formation, the method comprising:

(a) providing a downhole tool including at least one transmitter deployed in the borehole, the downhole tool further including a receiver array having a plurality of receivers longitudinally spaced from the at least one transmitter;

(b) propagating a first acoustic signal in the borehole using the at least one transmitter;

(c) receiving a first set of waveforms from the first acoustic signal at the receiver array;

(d) processing the first set of waveforms to determine the compressional wave velocity of the subterranean formation;

(e) propagating a second acoustic signal in the borehole using the at least one acoustic transmitter, the second acoustic signal being a multi-pole acoustic signal;

(f) receiving a second set of waveforms from the second acoustic signal at the receiver array;

(g) processing the second set of waveforms to determine a borehole guided wave velocity; and

(h) processing the borehole guided wave velocity and the compressional wave velocity of the subterranean formation to determine the shear wave velocity of the subterranean formation.

23. The method of claim 22, wherein the downhole tool includes first and second transmitters.

24. The method of claim 23, wherein:

the first acoustic signal is propagated in (b) by the first transmitter; and

the second acoustic signal is propagated in (e) by the second transmitter.

25. The method of claim 23, wherein the first and second transmitters are deployed at substantially the same longitudinal position on the downhole tool.

26. The method of claim 23, wherein the first and second transmitter are deployed at first and second longitudinal positions on the downhole tool.

27. The method of claim 22, wherein the first borehole guided wave has a center frequency in a range from about 12 kHz to about 16 kHz.

28. The method of claim 22, wherein the second borehole guided wave has a center frequency in a range from about 6 kHz to about 8 kHz and a bandwidth less than about 1.2 kHz.

29. The method of claim 22, wherein the second acoustic signal includes at least two waveforms selected from the group consisting of monopole, dipole, and quadrupole waves.

30. The method of claim 22, wherein (h) comprises:

processing a mathematical model to relate a theoretical shear wave velocity to a theoretical borehole guided wave velocity; and

processing the mathematical model, the borehole guided wave velocity determined in (g), and the compressional wave velocity determined in (d) to determine the shear wave velocity of the subterranean formation.

31. The method of claim 30, wherein the mathematical model is dependent upon an azimuthal order of a theoretical borehole guided wave.

32. A system for determining a shear wave velocity of a subterranean formation, the system comprising:

a down hole tool including an acoustic transmitter and at least one acoustic receiver, the tool operable to be positioned in a borehole such that the acoustic transmitter and the at least one acoustic receiver are located at corresponding first and second positions in the borehole; and

a processor configured to:

(A) instruct the transmitter to propagate a multi-pole acoustic signal into the borehole;

(B) instruct the at least one receiver to receive an acoustic waveform from the multi-pole acoustic acoustic signal;

(C) process the acoustic waveform to determine a borehole guided wave velocity; and

(D) process the borehole guided wave velocity to determine the shear wave velocity of the subterranean formation.